DEVELOPMENT OF PRE-CRASH ACTIVE SEATBELT SYSTEM FOR REAL WORLD SAFETY

Hideo Tobata
Hideo Takagi
Chinmoy Pal
Shunichi Fukuda
Nissan Motor Co., Ltd.
Japan
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ABSTRACT

In this paper, potential benefits of a brake operated pre-crash active seatbelt system are analyzed with experimental verifications and numerical simulations. The system is activated at the time of emergency braking operation.

The statistical data from real world accidents (Japan) as well as driving simulator analysis show that drivers interact with the brake to avoid crash in about 50% of the total number of accidents. This indicates that an inevitable crash can be detected before the actual time of crash by observing the emergency braking operation activated by the driver.

Experimental results show that restriction of occupant's forward movement is achieved by activating the system while braking. Numerical simulation results show that the reduction of chest injury parameters is expected due to restriction of occupant's forward movement. It is also confirmed that higher initial tension of the seat belt reduced both chest deceleration and displacement.

INTRODUCTION

Significant improvements have been achieved in the field of occupant protection both on car crashworthiness and respective restraint system development. Many active safety devices, such as emergency brake assist, stability control systems and ABS, have been provided in order to help the driver in avoiding a crash or to help reduce the collision severity. However, present technological advancement is encouraging the development of systems to be activated in pre-crash phase to help achieve further improvement and enhancement of vehicle safety.

In order to design an efficient pre-crash active safety system, thorough analysis on how drivers behave in accident situations is required. Deployment of these systems must be carefully judged and activated only when the driver really needs the assistance in most critical situations without any loss of driving pleasure or conflict with the drivers' natural behavior.

A part of this experimental system is, however, already demonstrated in NISSAN ASV-2 promoted by Ministry of Land, Infrastructure and Transport in synchronization with other advanced related safety systems on-board at the end of 2000 [5,6].

Concept and Configuration

<u>Statistical Data from Real World Accidents</u>

The statistical data [1] from real world accidents involving Nissan vehicles in Japan show that drivers interact with the brake to avoid crashes in about 43% of the total number of accidents causing fatal and serious injuries. In these accidents, 58% of occupants who received fatal or serious injuries were belted. From these statistical data, a seat belt pre-tensioner activated by detecting braking prior to impact, can be deployed in about 25% of these accidents. However, the above figures will vary from country to country. A detailed description can be found in previous literatures of 2-4. Therefore, judging emergency braking may be used as a trigger to activate any pre-crash safety device [5].

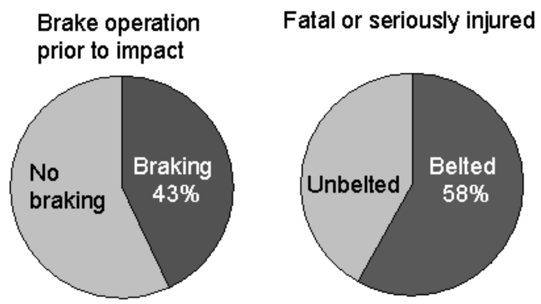

Figure 1. Nissan's accident research analysis related to its own vehicles involved in crash.

Overview of the Present System

The system consists of (i) brake pedal stroke sensor, (ii) electronic control unit, and (iii) motorized seat belt retractor (motor retractor). The main feature of the system is that the motor retractor will be activated when emergency braking operation is detected by measuring the brake pedal stroke pattern and vehicle speed.

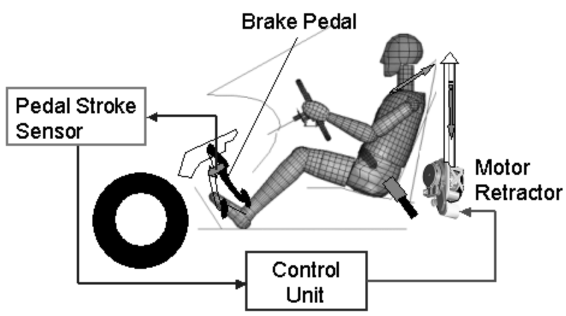

Figure 2. Schematic diagram of the present pre-crash active seatbelt system.

In a frontal crash, occupants in a car will be subjected to inertia when emergency braking is applied. This system can help reduce this forward movement of occupants and may be able to help improve occupants' position in emergency braking situation.

Two main important system design parameters of this system are (i) the timing at which the system activates the motor retractor and (ii) the amount of seat belt tension or retraction to be activated in order to help minimize the extra forward movement of occupants.

The system could help keep occupants in a better position from the view point of passive restraint systems before the crash. The system may also be able to help enhance the initial restraint force acting on the occupants at the early stage of crash, and subsequently this helps reduce the risk of injury during and after the crash.

Motor torque is transmitted to seat belt webbing via reduction gear and clutch system. When the electronic control unit judges emergency braking, the electronic control unit supplies the required amount of input current to the motor attached to the retractor. At the same time, a clutch system incorporated inside the retractor works to transmit motor torque to the seat belt reel and the seat belt reel winds seat belt webbing. The motor retractor and reduction gear together form a single compact unit.

Detection of Emergency Braking

Brake pedal stroke is measured with a brake pedal stroke sensor. The sensor signal is input to the electronic control unit. The electronic control unit calculates the brake pedal stroke speed and judges the degree of emergency or severity of the braking operation.

Figure 3 shows close correlation between brake pedal stroke and vehicle deceleration. From this figure, the degree of emergency or severity of the braking operation can be judged by measuring brake pedal stroke.

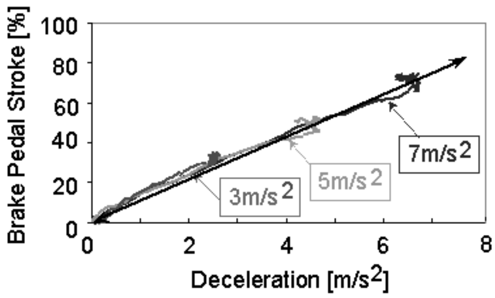

Figure 3. Correlation between brake pedal stroke and vehicle deceleration.

In the real world, different situations occur so, not only the speed of brake pedal stroke but also the length of stroke varies with type and situation of emergency. Therefore, emergency braking should be judged according to the combination of them. The basic idea of detecting emergency braking is described below in figure 4.

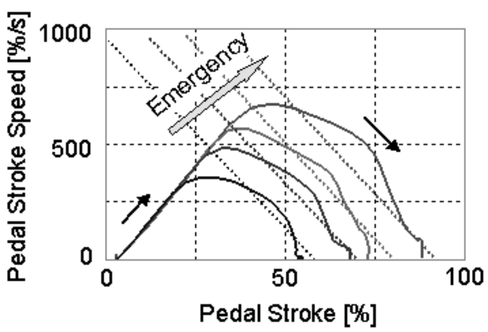

Figure 4. Brake pedal stroke vs. pedal stroke speed characteristic curve in braking operation.

Figure 5 shows the comparison of time history of brake pedal stoke and the deceleration of the vehicle. It indicates that there exists a time lag of 50msec (approx.) between the application of brake and the deceleration. Therefore, the driver's interaction with brake pedal can be used as triggering switch without any delay in activation. This also helps ensure higher degree of occupant protection in real world safety at the time of the emergency.

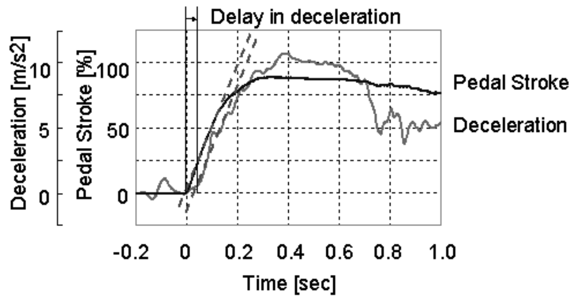

Figure 5. Comparison of time history of brake pedal stroke and vehicle deceleration

Experiments Results

<u>Evaluation Method of the System</u>

Experiments conditions were broadly divided into two types: (i) the fixed static test and (ii) on-board dynamic test at different speeds with different level of emergency brake, as shown in figure 6.

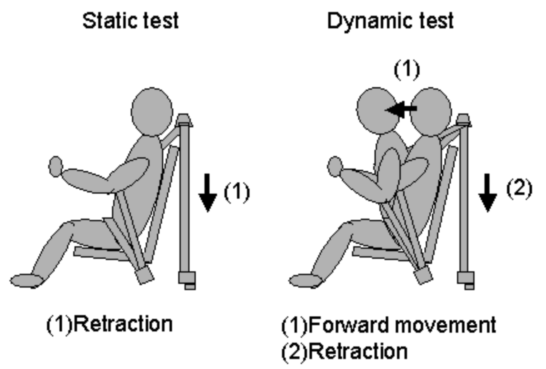

Figure 6. Static and dynamic tests.

In the static test, forward movement of occupants is zero. This was mainly performed to check the retraction performance (speed, durability, smoothness of loading and unloading operations, etc.) of the motor retractor.

On the other hand, the dynamic test induces forward movement of occupants through inertia. This means the dynamic test results can be affected by occupants' size, seating position (driver or passenger) and degree of deceleration. Therefore, the performance of the system in the real world during emergency braking can be evaluated only in dynamic tests.

Retraction Performance in Static Test

The seat belt retraction results in removing webbing by creating tension in it. The maximum applied tension of 300N in the present test covering the sustainable range within occupants' tolerance limit. Since, no saturation level in retraction vs. tension characteristic-curve was observed, as shown in figure 7.

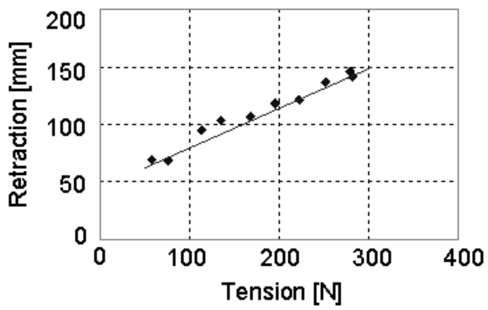

Figure 7. Retraction performance of motor retractor.

This linear upward monotonic increase of shoulder belt tension with the increase of retraction length clearly indicates that upper limit of the seat belt tension should be set or adjusted in accordance to occupants' tolerance limit.

Influence of Belt Tension on Occupant's Forward Movement in on-board Dynamic Test

Experimental results show that restriction of occupant's forward movement may be achieved by activating the motor retractor in emergency braking. Forward movement, measured at the chest mid-point of the occupant, and the corresponding belt retraction length with and without application of the motor retractor are shown in figures 8 and figure 9, respectively.

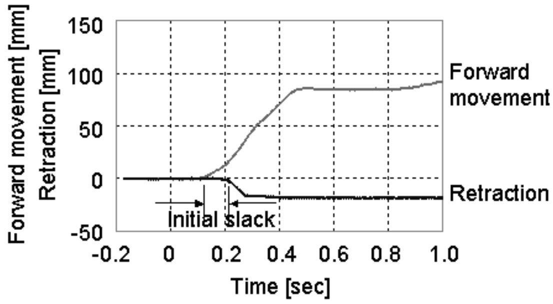

Figure 8. Occupant's forward movement and webbing movement without motor retractor.

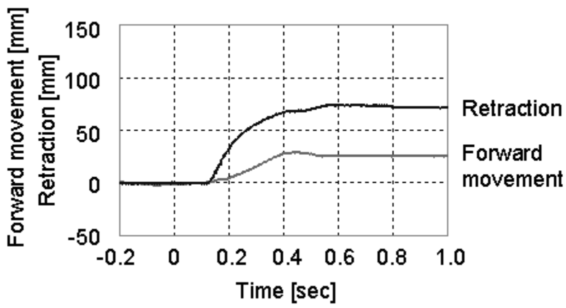

Figure 9. Occupant's forward movement and webbing retraction with motor retractor.

In the case of no motor retractor activation, the retraction length becomes minus (approx. –20mm) which means the seat belt is slightly extended as it is locked by webbing locking device.

On the other hand, with the activation of the motor retractor, retraction length becomes positive and the occupant's forward movement was reduced as some amount of belt is pulled in (approx. 75mm).

Estimation of Occupant Injury in Sled-Test

Besides reduction of occupants' forward movement, initial restraint was improved with the motor retractor. In the normal use of seat belt, the belt may not be tensed around the occupant. A motor retractor can help tighten the belt around the occupant. This can result in earlier restraint of occupants at the event of crash and consequently helps reduce chest forward movement and chest deceleration as shown in figure 10.

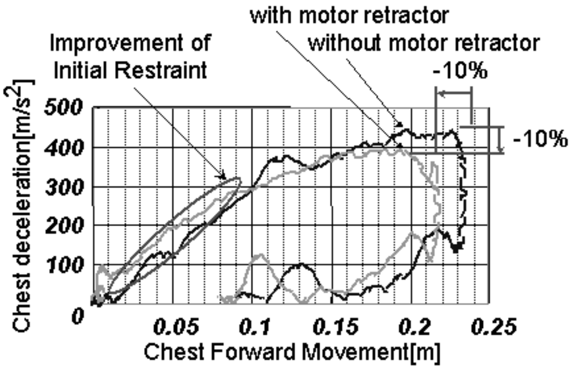

Figure 10. Performance of initial belt restraint in full-lap frontal test condition with air bag and pyro-pretensioner (validated by experiment and simulation).

Early restraint could make it possible to absorb more occupant energy with the seat belt in early stage of a crash and then the residual amount of energy can be absorbed with less excursion of the chest at the later stage of crash. This results in the reduction of the peak value of chest deceleration as well as forward movement. The restraint-efficiency of the seat belt, as measured by the linearity factor, is improved approximately by 5%. The linearity factor can be determined by the ratio of the area under deceleration –displacement G-S curve and corresponding area calculated by multiplying maximum deceleration with maximum displacement.

From these experiments results, a motor retractor was proved to be an efficient tool to help reduce the occupant's forward movement and to help improve initial restraint.

Overall occupant restraint performance during the crash phase, including HIC, can then be effectively tuned in conjunction with the air bag design.

Results of Numerical Simulation

<u>Method of Numerical Simulation</u>

Numerical simulation was conducted on the assumption that a driver activated the brake prior to collision as shown in Figure11.

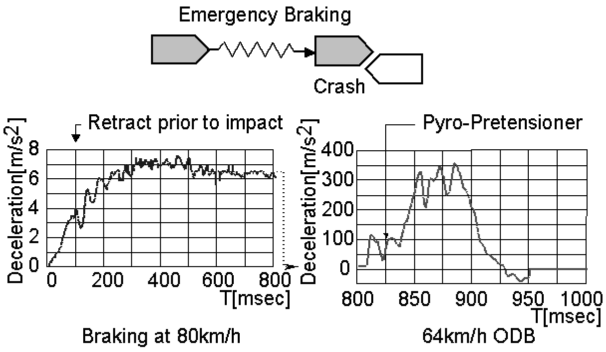

Figure 11. Conditions of numerical simulation.

This indicates a situation of applying a stiff 7m/s^2 brake with an initial velocity of 80 km/h before it crashes at 64 km/h ODB test conditions to simulate an 56km/h offset car-to-car crash in real world. The initial dynamic behavior or movement of the vehicle before crash, was measured by experiments. This experimental data were used as initial conditions of MADYMO simulation [7].

The initial position of the occupant was considered as the most critical parameter in this estimation. For both cases of with and without the motor retractor, the initial positions of occupants are shown in figure 12.

Numerical simulations were performed with a pyro-pretensioner and an air bag in standard AM50 HYBIII-MADYMO dummy model.

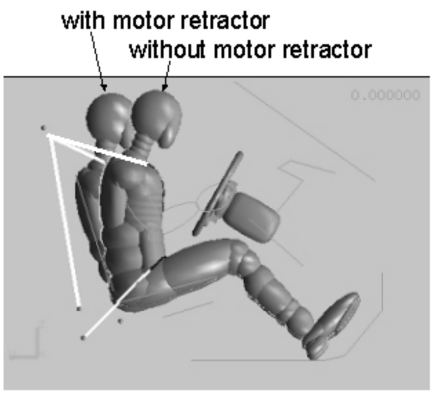

Figure 12. Change in initial position of a dummy before crash (numerical simulation).

Forward Movement of Occupant

Numerical simulation results show that the reduction of injury risk is expected due to restraint of the occupant’s forward movement in emergency braking. Thus, the forward movement of occupant in the event of crash could be reduced. This means that the possibility or risk of secondary impact between the occupants and the interior of a car could be reduced in certain crashes. With more seat belt retraction, there is less occupant forward movement as shown in figure 13.

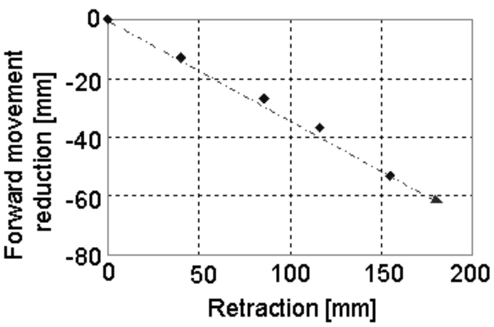

Figure 13. Forward chest movement reduction by seat belt retraction by motor retractor.

Injury Risk

Figure 14 and figure 15 confirm that the more belt retraction, the lower the chest deceleration and displacement.

The decrease in chest displacement is observed due to less thrust or contact force with the deployed air bag during the later stage of impact. In other words, the reduction of occupants’ forward movement may not only cause a delay in time of contact but also the duration of contact which can be optimized accordingly to help achieve the best possible restraint performance.

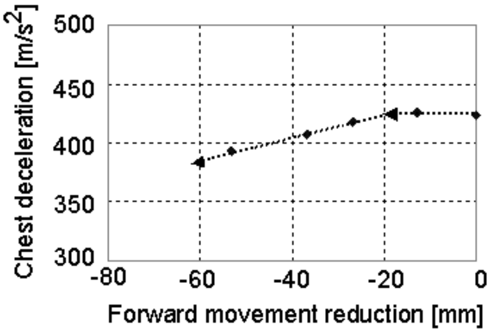

Figure 14. Improvement in occupant's chest deceleration.

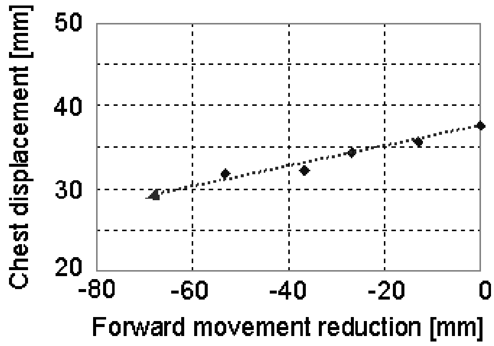

Figure 15. Improvement in occupant's chest displacement.

CONCLUSION

An overview of the present pre-crash active seatbelt system is described. The system is activated when emergency braking is detected. Based on Nissan accident research analysis, the implementation of this system is expected to help enhance occupant safety in the real world.

The system performance was verified by experimental results. These data include forward movement of occupants, seat belt tension and length of retracted webbing. Static tests are performed to set the broad specification of the motor retractor and also to check the different operation modes. From the dynamic tests, the performance in real world occupant safety can be estimated. A decrease of occupant's forward movement indicates that the risk of secondary injury could be reduced due to the effectiveness of initial restraint performance. Predicted numerical simulation results support experiment results. The forward movement of occupants, chest deceleration, and chest displacement in the event of crash are basically functions of occupants' position prior to impact and retraction. The results showed the tendency of lower injury level with more retraction in certain dynamic conditions.

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